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Full Length Research Paper

Assessment of health risks associated with organochlorine pesticides levels in processed fish products from Lake Victoria

Alex Wenaty^{1*}, Arvid Fromberg², Faith Mabiki³, Bernard Chove¹, Anders Dalsgaard⁴ and Robinson Mdegela⁵

¹Department of Food Technology, Nutrition and Consumer Sciences, College of Agriculture, Sokoine University of Agriculture, P. O. Box 3006, Morogoro, Tanzania.

²Department of Food Analytical Chemistry, National Food Institute, Technical University of Denmark (DTU), Kemitorvet, 2800 Kgs, Lyngby, Denmark.

³Department of Chemistry and Physics, Solomon Mahlangu College of Science and Education, Sokoine University of Agriculture, P. O. Box 3038, Morogoro, Tanzania.

⁴Department of Veterinary and Animal Sciences, Faculty of Health and Medical Sciences, University of Copenhagen, Groennegaardsvej 15, DK – 1870, Frederiksberg C, Denmark.

⁵Department of Veterinary Medicine and Public Health, College of Veterinary Medicine and Biomedical Sciences, Sokoine University of Agriculture, P. O. Box 3021, Morogoro, Tanzania.

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This study assessed the health risks of organochlorine pesticides in fish products from Lake Victoria. Nine organochlorine pesticides (α - Hexachlorocyclohexane (HCH), β - HCH, γ - HCH (Lindane), Hexachlorobenze (HCB), Dieldrin, p, p'- DDE, α - endosulfan, Oxychlordane and α - chlordane) were identified at variable levels in fish products. Of the nine organochlorine pesticides which were identified, p, p'- DDE (3.73 μ g/kg) was the highest in deep fried Nile tilapia while the lowest amount was α - HCH (0.14 μ g/kg) in smoked Nile tilapia. In the smoked products, several of the organochlorine pesticides were detected at high concentrations. This is attributed to the fact that organochlorine pesticides are fat soluble and therefore found in the lipid phase of the fish during smoking. There were high levels and prevalence of p, p'- DDE, α - endosulfan, HCB, Dieldrin and Lindane in deep fried Nile tilapia compared to other fish products probably due to environmental contamination. However, the levels of organochlorine pesticides in this study are below the maximum residual limits (MRLs) set by FAO/WHO for fish products indicating that the fish products were safe for human consumption and do not present health risks in terms of organochlorine pesticides residues.

Key words: Cancer risk, hazard index, Kayabo, organochlorine pesticides, trims.

INTRODUCTION

Organochlorine pesticides (OCPs) such as Hexachlorocyclohexanes (HCHs), Hexachlorobenzene Dichlorodiphenyltrichloroethane (DDTs), (HCB), Aldrin, Dieldrin and Endosulfans are products

*Corresponding author. Email: wenatyalex@sua.ac.tz.

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used for plant protection, pest control and preservation of foodstuffs during storage, and the residues derived from their use may be found in food products (Biego et al., 2010). They have also been used extensively in mosquito, termite and tsetse fly control programs (Farshid et al., 2012). In Tanzania, endosulfans are still used for agricultural purposes such as in cotton fields and horticultural production while DDTs are used to control mosquito populations to fight malaria (Henry and Kishimba, 2006; Polder et al., 2014; Mahugija et al., 2018). Organochlorine compounds are highly lipophilic (Farshid et al., 2012; Polder et al., 2014), persist in the environment (El-Mekkawi et al., 2009; Ssebugere et al., 2014a), readily transported over longer distances and tend to bioaccumulate through the food chain (Guzzella et al., 2005; Henry and Kishimba, 2006; Biego et al., 2010). The compounds accumulate in living organisms and are known for their carcinogenic, mutagenic and teratogenic effects. They also affect the nervous, immune, reproductive, renal and hepatic systems (Biego et al., 2010; Polder et al., 2014).

Lake Victoria is one of the most important water resources in Tanzania and neighbouring countries. The local communities dwelling around the lake use it as a major source of household and industrial water supply, irrigation water for agricultural production, facilitates boat transport and provides for fishing as a main source of animal derived protein as well as income. Several agricultural related activities involving the use of pesticides are practiced in large areas around the Lake Victoria basin (Polder et al., 2014). There are also numerous rivers and streams crossing through the fields discharging into the Lake Victoria basin suggesting that they may carry pesticides into the lake. Thus, Lake Victoria is receiving a considerable amount of pollution because of anthropogenic activities that are undertaken along the lake such as agricultural and industrial activities (Ssebugere et al., 2014a). In addition to that, due to the solubility of the pesticides in fat and lipids, fish and other aquatic organisms concentrate and accumulate pesticide residues in their fatty tissues (Mahugija et al., 2018).

Studies to assess the chemical and microbiological quality of fish and fishery products in Lake Victoria have focused mainly on fish products that are intended for export to Europe and other developed countries (Manirakiza et al., 2002; Henry and Kishimba, 2006; Kasozi et al., 2006; Darko et al., 2008; Kirema–Mukasa, 2013; Polder et al., 2014; Ssebugere et al., 2014b; Oluochi-Otieno et al., 2016; Baniga et al., 2017). Some of the studies have as well been limited in scope as they have been focusing on only few persistent organochlorine compounds (Henry and Kishimba, 2006; Polder et al., 2014). Few studies have documented the quality of fishery products such as salted and sundried Nile perch (*Kayabo*) in terms of microbiological quality and physico-chemical properties (Baniga et al., 2019). These products are highly consumed by low and middle-income

communities in domestic and regional markets in countries like the Democratic Republic of Congo, Rwanda, Burundi, Malawi, Kenya and Uganda (LVFO, 2013).

This study aimed to determine the prevalence and levels of organochlorine pesticides in processed fish products from Lake Victoria as well as the human health risks associated with consumption of such products.

MATERIALS AND METHODS

Description of the study area

The study was conducted at the Kirumba fish market in Mwanza between May and August 2017. The market is the largest fish market in the lake zone receiving fish products from all regions on the Tanzanian side of Lake Victoria. Fish folks and processors bring their fish products to the market where they are sold to middle men that then deliver the products to different markets in Tanzania and outside the country, for example in Uganda, DRC, Burundi, Rwanda, Zambia, Kenya and Malawi where they are an important source of protein and income (LVFO, 2013).

Fish samples collection and extraction

Six products of fish samples that is, salted and sundried Nile perch commonly known as *Kayabo*, trims of Nile perch, smoked Nile perch and Nile tilapia and deep fried products of both Nile perch and Nile tilapia were collected from randomly selected fish processors and sellers at the market. A total of 360 samples of fish products (that is 60 samples of each product) were collected for analysis of OCPs. Extraction and cleanup for determination of OCPs in fish samples were done using a modified quick, easy, cheap, effective, rugged and safe (QuEChERS) procedure at the National Fish Quality Control Laboratory in Mwanza, Tanzania. Thirty grams of each sample were measured in triplicates and homogenized using a blender. Fifteen grams of the homogenized samples were transferred into 100 mL centrifuge tubes as described by Wenaty et al. (2019). Thereafter, 2.5 g of sodium bicarbonate (NaHCO_3), 60 mL of ethyl acetate and 15 g of anhydrous Na_2SO_4 were added and placed in a shaking machine to homogenize for 20 min. The supernatants were transferred into 15 mL centrifuge tubes containing 0.125 g of primary secondary amine (PSA) and 0.75 g of anhydrous MgSO_4 (Anastassiades et al., 2003; Wenaty et al., 2019). The mixture was centrifuged at 2500 rpm for 10 min and left to separate for further 5 min. The supernatants were transferred into vials and then transported to Denmark (Technical University of Denmark (DTU)), for analysis. Prior to gas chromatographic (GC) analysis, the supernatants were evaporated with a gently stream of nitrogen to almost dryness and the solvent was changed to isooctane ready for GC analysis.

Chemical analysis

Chemical analysis was performed at the laboratory of Food Analytical Chemistry at the DTU. The collected fish samples were analysed for 19 OCPs namely; p, p'- DDT, o, p- DDT and metabolites p, p'- DDE and p, p'- DDD, α -HCH, β -HCH, γ -HCH (Lindane), HCB, Heptachlor, Heptachlor epoxide, Aldrin, Dieldrin, Endrin, Isodrin, α -Endosulfan, Oxychlordane, γ -Chlordane, α -Chlordane and Transnonachlor. Most of the studied OCPs are listed in the Stockholm Convention on persistent organic pollutants (POPs) for initial elimination and reduction in use because of their

adverse effects on the environment as well as living organisms (Polder et al., 2014).

Identification and quantification of organochlorine pesticides

Separation and detection of OCPs were performed on a Hewlett Packard Gas Chromatography (Agilent 6890 Series gas chromatography system; from Agilent Technologies) equipped with an auto sampler (Agilent 7683 Series; from Agilent Technologies). For optimum separation, a dual capillary column system with two separate columns of different polarity and selectivity were used (Chrompac CP – sil 5CB and J and W DB- 17), Nominal length 50 and 60 m respectively, 0.25 mm ID, 0.25 µm film thickness) and coupled to two ⁶³Ni electron capture detectors (Agilent 6890 ECD) as described by Wenaty et al. (2019). The following GC conditions were used; injector temperature: 280°C; injection volume: 2 µL; injector mode: splitless; purge flow: 42 mL/min; purge time: 0.60 min; carrier gas: Helium; constant flow: 2.0 and 1.3 mL/min respectively and make up gas: Nitrogen. The temperature programme was 90°C held for 2.0 min; 30°C/min increased to 170°C held for 7.5 min; 2.0°C/min increased to 185°C; 3.0°C/min increased to 220°C held for 15 min; 3.0°C/min increased to 255°C held for 2.0 min and 5.0°C/min increased to 280°C held for 10 min. The detector temperature was 300°C (Wenaty et al., 2019).

Analytical quality control

To maintain the quality of analytical results, blanks and standards were analysed after every analysis of five samples. The limits of detection (LODs) of the analytes were calculated as concentrations whose peaks were three times the peaks of signal to noise (S/N) ratios while their corresponding limits of quantification (LOQs) were determined as concentrations whose peaks were ten times the peaks of signal to noise (S/N) ratios.

Data analysis

Statistical analysis used for the data analyses include subjecting the measured OCPs data to descriptive statistics in order to deduce the minimum, maximum, mean concentrations and standard deviations of the detected OCPs (SPSS Version 16). Data on OCP concentration were presented as mean ± SD. ANOVA was used to compare concentrations between fish products and the means were separated using Duncan's Multiple Range Test. In data processing, the concentrations of OCPs in samples below the limit of detection (<LOD) were treated as zero. Significant difference was declared at $p < 0.05$ for all analyses.

Risk assessment model

The estimated dose (CDI) received through consumption of fish products was calculated using Equation 1 and the cancer risk (C_R) using Equation 2, adopted from the Environmental Protection Agency (USEPA, 1997, 2009) of the United States.

$$CDI = \frac{C * CR * EF * ED}{BW * AT} \quad (1)$$

$$C_R = SF * CDI \quad (2)$$

For non-carcinogenic risks, the hazard quotients (HQs) of each organochlorine pesticide measured were calculated by using

Equation 3 and the hazard indices (HI) were calculated using Equation 4.

$$HQ = \frac{CDI}{RfD} \quad (3)$$

$$HI = \sum HQs \quad (4)$$

Where: CDI (mg/kg-day) is the estimated chronic daily intake; C_R is the cancer risk via consumption of contaminated fish products; C (mg/kg) is the measured concentration of OCPs in fish products; IR (kg/day) is the consumption rate; HI (mg/kg-day) is the hazard index (overall non-cancer risk via consumption of contaminated fish products); HQ (mg/kg-day) is the hazard quotient (individual compound non-cancer risk via consumption of contaminated fish products); EF is the exposure frequency, 365 days/year (USEPA, 2009); ED is the exposure duration, 60 years for adults and 12 years for children (USEPA, 2009); SF is the cancer slope factor in this study, $2 \text{ (mg/kg-day)}^{-1}$ (Ge et al., 2013) for all OCPs detected; RfD is the reference dose (mg/kg-day), varied from one organochlorine pesticide to another; BW is the hypothetical average body weight in this study, 70 kg for adults and 29 kg for children (USEPA, 2001); AT is the averaging time, 60 years × 365 days/year = 21900 days for adults and 12 years × 365 days/year = 4380 days for children (US EPA, 2001; Ge et al., 2013).

Qualitative descriptions of lifetime cancer risks were based on Agency of Toxic Substances and Disease Registry (ATSDR) standards as follows; very low when the estimated value is $\leq 10E-06$, low: $10E-06 < \text{value} \leq 10E-04$, moderate: $10E-04 < \text{value} \leq 10E-03$, high: $10E-03 < \text{value} \leq 10E-01$ and very high when the estimated value is $\geq 10E-01$ (ATSDR, 1995, Ge et al., 2013). For non-carcinogenic risks, HI, calculated as sum of HQs greater than one was considered risky while HI less than one was considered no risk associated with consumption of fish products.

RESULTS AND DISCUSSION

Concentrations of organochlorine pesticides

The concentrations of the detected organochlorine pesticides in the analysed processed fish products are shown in Table 1. Of the 19 OCPs measured, only nine (α -HCH, β -HCH, γ -HCH (Lindane), HCB, Dieldrin, p, p'-DDE, α -endosulfan, Oxychlordane and α -chlordane) were detected. The LODs of the detected components ranged between 0.01 and 0.40 µg/kg whereas their corresponding LOQs ranged between 0.04 and 1.30 µg/kg. Alfa (α -HCH) was detected in salted and sundried Nile perch and smoked products of Nile perch and Nile tilapia. The highest mean concentration was 0.54 µg/kg being detected in salted and sundried products, while the lowest mean concentration was 0.14 µg/kg in smoked Nile tilapia. The trims, deep fried Nile perch and Nile tilapia products had no detectable (<LOD) levels of α -HCH.

Beta (β -HCH) was detected in only one fish product (smoked Nile perch) at 1.43 µg/kg. The other five fish products (smoked Nile tilapia, salted and sundried Nile perch, trims, deep fried products of Nile perch and Nile tilapia) had no detectable (<LOD) concentrations of β -

Table 1. Concentration of organochlorine pesticides ($\mu\text{g/kg}$) in fish products collected from Kirumba fish market in Mwanza.

OCPs	Sample					
	Kayabo	Trims	Smoked Tilapia	Smoked Nile perch	Deep fried Nile perch	Deep fried Tilapia
α - HCH	0.54 \pm 0.02 ^b	<LOD	0.14 \pm 0.06 ^a	0.39 \pm 0.01 ^b	<LOD	<LOD
β - HCH	<LOD	<LOD	<LOD	1.43 \pm 0.18 ^a	<LOD	<LOD
Lindane	1.15 \pm 0.05 ^a	<LOD	0.44 \pm 0.08 ^b	0.99 \pm 0.05 ^a	1.00 \pm 0.04 ^a	0.52 \pm 0.02 ^b
HCB	0.66 \pm 0.10 ^a	<LOD	0.31 \pm 0.08 ^b	1.66 \pm 0.38 ^a	<LOD	2.03 \pm 0.03 ^a
Dieldrin	<LOD	<LOD	0.71 \pm 0.10 ^a	0.66 \pm 0.08 ^a	<LOD	0.78 \pm 0.08 ^a
p, p'-DDE	2.02 \pm 0.11 ^{bc}	1.74 \pm 0.71 ^{bc}	2.50 \pm 0.34 ^b	1.07 \pm 0.23 ^c	2.17 \pm 0.16 ^b	3.73 \pm 0.31 ^a
α -endosulfan	<LOD	<LOD	<LOD	0.65 \pm 0.03 ^a	<LOD	<LOD
Oxychlordane	<LOD	<LOD	<LOD	0.39 \pm 0.03 ^b	<LOD	<LOD
α - chlordane	<LOD	<LOD	0.68 \pm 0.04 ^b	0.89 \pm 0.02 ^a	<LOD	<LOD

Means on the same row with different superscript are significantly different at $p < 0.05$, <LOD- below the limit of detection (0.01 – 0.40 $\mu\text{g/kg}$).

HCH.

Lindane (γ - HCH) was found at detectable levels in 5/6 fish products including salted and sundried products of Nile perch, smoked products of both Nile perch and Nile tilapia and deep fried products of both fish species. The highest concentration was detected in salted and sundried products at 1.15 $\mu\text{g/kg}$ while the lowest was 0.44 $\mu\text{g/kg}$, being detected in smoked products of Nile tilapia. Fish trims were free from γ - HCH. The concentrations of Lindane in all fish products were below the maximum residual limit (MRL) of 100 $\mu\text{g/kg}$ set for fishery products (Biogo et al., 2010). The levels of HCHs determined in this study were far higher than those that were determined by Wenaty et al. (2019) in fresh species of *L. niloticus* and *O. niloticus* from the same study area. In a study by Wenaty et al. (2019), the levels of α - HCH and γ - HCH were below their lowest limits of detection (LODs) in both fish species while the concentration of β - HCH was up to 1.19 $\mu\text{g/kg}$ in *L. niloticus* and 0.60 $\mu\text{g/kg}$ in *O. niloticus*. Detection of high levels of HCHs in processed fish products than fresh fish muscles suggests that contamination occurs during fish processing in the value chain. However, the levels of HCHs detected in this study are far lower than the levels of the same that were detected in the Ugandan side of Lake Victoria where the concentrations ranged between 5.7 and 26 $\mu\text{g/kg}$, between 7 and 34 $\mu\text{g/kg}$ and between 5 and 13 $\mu\text{g/kg}$ for α - HCH, β - HCH and γ - HCH respectively (Ssebugere et al., 2014 a,b; Wenaty et al., 2019).

The ratio of α – HCH to γ – HCH in the fish products where these components were detected simultaneously ranged from 0.32 to 0.47. The ratios are normally used to establish whether degradation of technical HCH in the environment or food items is efficient and whether there is recent or past application of technical HCH in the study area. High ratios of α – HCH/ γ – HCH ranging from 4 to 7 are used to indicate fresh inputs of technical HCH in the environment or food items, while lower (<3) ratios suggest a historical use of Lindane in the area from which the samples originated (Yi et al. (2013) and Ssebugere et

al. (2014a, b). The low ratios found in this study (0.32 – 0.47) suggest past exposure of the fish products to Lindane. Furthermore, the sum of HCHs concentrations found in the fish products were below the extraneous maximum residue limit (EMRL) of 5000 $\mu\text{g/kg}$ set by FAO/WHO Codex Alimentarius Commission for fish and other fisheries products (FAO/WHO, 1997). The fish products that were considered in this study are therefore safe for human consumption with reference to HCHs residues.

Hexachlorobenzene (HCB) was observed in four out of six fish products as presented in Figure 1. There were high concentrations of HCB in deep fried Nile tilapia (2.03 $\mu\text{g/kg}$) compared to other fish products, while the lowest detectable levels of HCB were detected in smoked Nile tilapia (0.31 $\mu\text{g/kg}$). The fish trims and deep fried Nile perch had no detectable (<LOD) levels of HCB. The highest concentration of HCB in this study was about four times higher than the highest concentration of HCB in fresh fish muscles in another study where 0.59 $\mu\text{g/kg}$ was found (Wenaty et al., 2019). The levels of HCB in this study were also in the same range as those detected by Polder et al. (2014) from four different lakes in Tanzania. The study by Polder et al. (2014) reported HCB levels in *O. niloticus* ranging from 1.4 to 4.0 $\mu\text{g/kg}$ (L. Victoria), 1.1 to 1.3 $\mu\text{g/kg}$ (L. Tanganyika), 1.2 to 2.9 $\mu\text{g/kg}$ (L. Nyasa) and 0.6 to 2.8 $\mu\text{g/kg}$ (L. Babati). It was further observed that the levels of HCB in Tanzanian fish is due to long-range atmospheric transport rather than local sources as there have been no historical use of HCB in Tanzania. The levels of HCB were far lower than the tolerable limits of 200 $\mu\text{g/kg}$ recommended by FAO/WHO suggesting that the fish products are safe for human consumption with respect to HCB levels. HCB is generally used as a pesticide and generated as a byproduct in industrial productions (Wang et al., 2013). Since there is no historical use of HCB in Tanzania (Polder et al., 2014), it may be that its presence in food items is due to its volatile nature and long-range atmospheric transport (Wenaty et al., 2019).

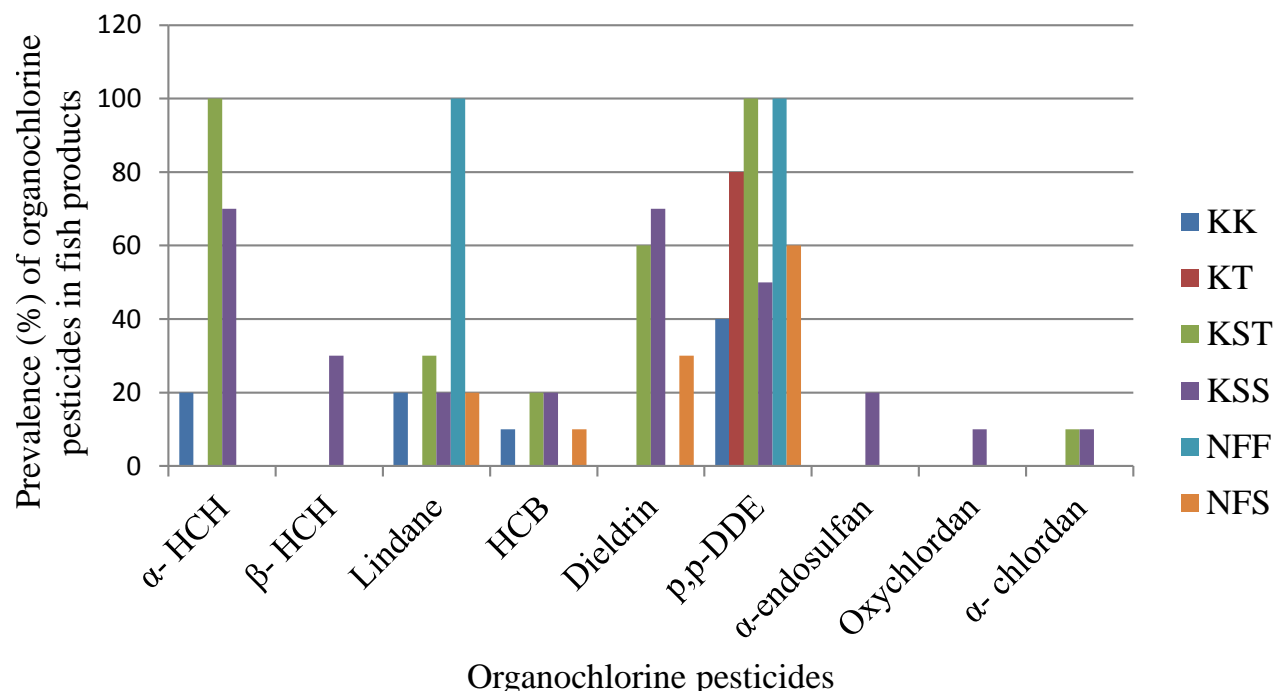


Figure 1. Prevalence (%) of organochlorine pesticides in existing processed fish products from Lake Victoria. KK- Salted and sundried (Kayabo), KT- Trims, KST- Smoked Tilapia, KSS- Smoked Nile perch, NFF- Smoked Nile perch and NFS- Smoked Tilapia.

Of the four cyclodienes analysed, only Dieldrin was detected in smoked products of Nile perch and Nile tilapia and deep fried products of Nile tilapia as shown in Table 1. The deep fried products contained higher concentrations (0.78 µg/kg) compared to other products, whereas smoked Nile perch had the lowest mean concentration (0.66 µg/kg) though the difference was not significant. Salted and sundried fish, trims and deep fried Nile perch products had no traces of Dieldrin. Aldrin and other drins residues were not detected in any fish products. This is because Aldrin is converted to Dieldrin once it enters the environment or the body of an organism by the action of sunlight and bacteria. Dieldrin is resistant to bacterial and chemical breakdown (Orris et al., 2000; Afful et al., 2013). Other drins such as Isodrin and Endrin are also unstable in the environment. The ratios of the detected Dieldrin to Aldrin residues (Dieldrin/Aldrin) are usually used to ascertain whether the detected residues are due to current applications of Aldrin or not (Madadi et al., 2006; Wenaty et al., 2019). Ratios <1 indicate current applications of Aldrin while ratios >1 indicate past applications of Aldrin. As Aldrin was not detected in any of the fish products, the ratios were not established. The concentrations of Dieldrin detected in the current study are in the same range as the concentrations that were detected in fresh fish species of *L. niloticus* and *O. niloticus*; whereby Dieldrin was up to 1.06 µg/kg, whereas the concentration of Aldrin was 0.34 µg/kg (Wenaty et al., 2019). However, the

concentrations of Dieldrin in the fish products were lower than the maximum residue limit (MRL) of 200 µg/kg recommended by the competent authorities for fish and other fishery products (Biogo et al., 2010).

Of the four isomeric DDTs analysed, only p, p'- DDE was found in all six fish products at variable concentrations as presented in Table 1. Deep fried products of Nile tilapia had the highest concentrations (3.73 µg/kg), while smoked Nile perch products had the lowest concentrations. The two DDT isomers; p, p'- DDT and o, p'- DDT were not detected at all. This is an indication of past use of DDT in the study area. Similarly, the other decomposition product p, p'- DDD was not detected. This observation implies that degradation of DDT in fish is an aerobic process that produces p, p'- DDE and not p, p'- DDD due to availability of oxygen (Kasozi et al., 2006). The concentrations of DDTs measured in the current study are far lower than the concentrations of these chemicals in fresh fish muscles which were detected by Henry and Kishimba (2006) in the same study area. Henry and Kishimba reported the levels of DDTs in fish species from Southern Lake Victoria up to 300 µg/kg, and the main source was the continued use of DDTs in agriculture and vector control programmes. The ratio of DDT to DDE+DDE is commonly used to establish whether there is current or past application of DDT (Liu et al., 2010; Kuranchie-Mensah et al., 2011; Bergkvist et al., 2012; Afful et al., 2013). In our study, the parent compound DDT was not

Table 2. Analysis of variance of the detected organochlorine pesticides residues in fish products.

OCPs	DF	F	P
α - HCH	2	10.40	0.001**
Lindane	4	24.14	<0.001**
HCB	3	16.32	0.010**
Dieldrin	2	0.42	0.667
p, p'-DDE	5	8.87	<0.001**
α - chlordane	1	31.29	0.031**

** Means are significantly different at 0.05 level. DF- Degree of freedom, F- F Value and P- P Value.

detected in any fish products, which indicates historical use of DDT, and therefore, the ratios were not established. The concentrations of DDT metabolites were far below the MRL of 200 $\mu\text{g/kg}$ recommended for fish and other fishery products (Biogo et al., 2010).

We analysed for three isomers of endosulfan; α -endosulfan, β - endosulfan and the degradation product; endosulfan sulfate, but only α - endosulfan was detected in one out of six fish products as described in Table 1. High α - endosulfan levels were detected in smoked Nile perch products (0.65 $\mu\text{g/kg}$) while other products had no detectable (<LOD) quantities of α - endosulfan. The presence of α - endosulfan in fish products indicates recent exposure of the fish products to the chemical through the food chain. However, β - endosulfan was not detected; this observation is probably due to variation of the two components in the technical endosulfan mixture that consists of 70% α - endosulfan and 30% β -endosulfan, with endosulfan sulfate being the decomposition product (Afful et al., 2013). Thus, in processed fish products, high concentrations of α -endosulfan than β - endosulfan could be anticipated.

Oxychlordane were detected at a mean concentration of 0.39 $\mu\text{g/kg}$ in only one fish product; smoked Nile perch product as depicted in Table 1. All other fish products which were considered for this study had levels of Oxychlordane below their limits of detection (<LOD). Presence of Oxychlordane residues in fish products is due to environmental persistence.

Two fish products that were considered in this study; smoked products of Nile perch (0.89 $\mu\text{g/kg}$) and Nile tilapia (0.68 $\mu\text{g/kg}$) had trace amounts of α - chlordane and Oxychlordane as described in Table 1. However, the detected Oxychlordane and α - chlordane were below the Codex Alimentarius Commission extraneous residual limits (EMRL) of 0.05 mg/kg set for products of animal origin as sum of *cis*- and *trans*- isomers and Oxychlordane and expressed as chlordane (EFSA, 2007).

Heat treatments such as deep frying seems to significantly reduce the levels of persistent organochlorine pesticides in fish, as this method of frying accelerates drying of the fillets and evaporation of water and

persistent organochlorine compounds due to the high temperature of the cooking oil, and by transfer of organochlorine compounds to the cooking oil which itself could be acting as an extraction solvent (Witczak, 2009). The deep fried fish products analysed contained high levels of organochlorine pesticides such as HCB, Dieldrin, p, p'-DDE and Lindane as compared to other products like trims, salted-sundried and smoked products probably due to environmental contamination that occurs along the food chain as seen in Table 1. Smoking of fish tends to increase the levels of persistent organochlorine compounds due to a decrease in co-distillation with steam and the penetration of the compounds with smoke to the fish meat (Witczak and Tomza- Marciniak, 2010; Witczak, 2012). Our findings support this as most of the smoked samples had significant quantities of different persistent organochlorine pesticides.

Analysis of variance of the detected organochlorine pesticides in fish products collected from the market are given in Table 2. Mean separations using Duncan's Multiple Range Test indicate significant differences ($p < 0.05$) of some OCP levels between fish products. For Oxychlordane, β - HCH and α - endosulfan, the means were not separated as they were detected in measurable levels in only one fish product each.

Evaluation of organochlorine residue levels

Table 3 compares mean organochlorine concentrations of the measured persistent organochlorine pesticides to MRLs recommended by some international statutory bodies for aquatic biota (Afful et al., 2013) and the OCP maximum residue concentrations found in fish meat in previous studies in Lake Victoria. Mean residue OCP levels were far lower (Henry and Kishimba, 2006) or in the same range (Polder et al., 2014) as compared with previous studies. The levels were also far below the MRL recommended by the European Food Safety Authority and Food and Agricultural Organization (FAO) of the United Nations as described in Table 3 for fish and other fishery products. Thus, persistent organochlorine

Table 3. Comparison of mean organochlorine pesticides concentrations ($\mu\text{g/kg}$) in processed fish products to other previous studies in Lake Victoria and maximum residual limits stipulated by some statutory agencies.

Compound	This work	Polder et al. (2014)	EFSA (2007)	Henry and Kishimb (2006)	FAO/WHO (1997)
Σ Chlordane	2.0	ND	50	ND	ND
Σ DDT	13.2	34.7	ND	30	300
Dieldrin	2.2	ND	ND	ND	300
α - HCH	1.1	ND	ND	ND	ND
β - HCH	1.4	ND	ND	ND	300
γ - HCH	4.1	ND	ND	ND	300
α - Endosulfan	0.7	94.3	ND	200	ND
HCB	4.7	2.5	ND	ND	200

ND means not determined.

pesticides do not seem to pose food safety health hazards to humans.

Prevalence of organochlorine pesticides in fish products

The percentage occurrence of the detected organochlorine pesticides in processed fish products from Lake Victoria Zone and other domestic and regional markets are shown in Figure 1. These pesticides were more prevalent in smoked fish products (Nile perch and Nile tilapia) compared to other type of fish products. The prevalence of the nine OCPs detected ranged from 0% (Oxychlordane) to 100% (α - HCH and p, p'-DDE) and 10% (α - chlordane) to 70% (α - HCH and p, p'-DDE) in smoked Nile tilapia and Nile perch products respectively. All the nine OCPs occurred in smoked Nile perch while six OCPs occurred in smoked Nile tilapia. A high OCP prevalence was also observed in deep fried Nile tilapia where four OCPs were detected.

The prevalence was followed by salted and sundried Nile perch products in which four OCPs were detected at measurable levels as follows; HCB (10%), α - HCH and Lindane (20%) and p, p'-DDE (40%). For deep fried Nile perch products, only Lindane (100%) and p, p'-DDE (100%) were detected at measurable quantities. The prevalence of p, p'-DDE was extremely high in all products ranging from 40% (for salted and sundried Nile perch products) to 100% (for smoked Nile tilapia and deep fried Nile perch). Oxychlordane was detected in only smoked Nile perch product. High prevalence of OCPs in smoked and deep fried fish products is an indication that the two heat treatment techniques are good methods for preservation of fish products in the sense that almost all the water is removed. Being lipophilic in nature, the OCPs are left in the fat-rich tissues of the fish mass. However, a low prevalence of OCPs could be anticipated in deep fried products compared to other products because at high temperature, the cooking oil acts as an extracting solvent extracting

most of the OCPs from the fish product (Witczak, 2009). The high prevalence of OCPs is probably due to contamination of fish products in the value chain.

Human health risk assessment

Human health risk assessment associated with consumption of organochlorine pesticides in the fish products was evaluated using Equations 1-4 and ATSDR standard for adults and children. As indicated in Table 4, the cancer risks for the detected OCPs for both adults and children were between $1\text{E-}06$ and $1\text{E-}04$. This observation indicates that there is a low cancer risks of OCPs associated with consumption of fish products from Lake Victoria with children found to have higher values of cancer risks than adults. Based on ATSDR standard, the cancer risks for OCPs in this study are between very low to low.

Table 5 shows the non- carcinogenic risks of OCPs associated with consumption of fish products from Lake Victoria. The HI which is given as a sum of HQs ranged between $3.7\text{E-}05$ and $1.0\text{E-}01$ for adults and between $4.4\text{E-}05$ and $1.2\text{E-}01$ for children. According to recommendations by USEPA (2009), the values were very low (<1), suggesting that the risks associated with consumption of the analysed fish products from Lake Victoria are insignificant for both adults and children.

Conclusion

This study reports the human health risks associated with organochlorine pesticides in fish products from Lake Victoria that are sold in the domestic and regional markets. The results show that some organochlorine pesticides are present in fish products because of contamination in the value chain. The levels of the identified organochlorine pesticides were far lower than the previously reported concentrations in the study area and the MRLs recommended for fish and other fishery

Table 4. Lifetime cancer risks for the nine organochlorine pesticides detected in fish products from Lake Victoria.

Fish sample	Kayabo		Trims		Smoked Tilapia		Smoked Nile perch		Deep fried Nile perch		Deep fried Tilapia	
OCPs	AD	CHI	AD	CHI	AD	CHI	AD	CHI	AD	CHI	AD	CHI
	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR
Oxychlordane	ND	ND	ND	ND	ND	ND	4.1E-06	1.0E-05	ND	ND	ND	ND
α-Chlordane	ND	ND	ND	ND	7.2E-06	1.7E-05	9.4E-06	2.3E-05	ND	ND	ND	ND
p, p'-DDE	2.1E-05	5.2E-05	1.8E-05	4.4E-05	2.6E-05	6.4E-05	1.1E-05	2.7E-05	2.3E-05	5.5E-05	3.9E-05	9.5E-05
Dieldrin	ND	ND	ND	ND	7.5E-06	1.8E-05	7.0E-06	1.7E-05	ND	ND	8.3E-06	2.0E-05
α- HCH	5.7E-06	1.4E-05	ND	ND	1.5E-06	3.6E-06	4.1E-06	1.0E-05	ND	ND	ND	ND
β- HCH	ND	ND	ND	ND	ND	ND	1.5E-05	3.7E-05	ND	ND	ND	ND
γ- HCH	1.2E-05	3.0E-05	ND	ND	4.7E-06	1.1E-05	1.1E-05	2.5E-05	1.1E-05	2.6E-05	5.5E-06	1.3E-05
α- Endosulfan	ND	ND	ND	ND	ND	ND	6.9E-06	1.7E-05	ND	ND	ND	ND
HCB	7.0E-06	1.7E-05	ND	ND	3.3E-06	7.9E-06	1.8E-05	4.2E-05	ND	ND	2.2E-05	5.2E-05

AD stands for adults, CHI for children, CR for lifetime cancer risk and ND for not determined, as their concentrations in fish products were <LOD.

Table 5. Non- carcinogenic risks of the nine organochlorine pesticides measured in fish products from Lake Victoria.

Fish sample	Kayabo		Trims		Smoked Tilapia		Smoked Nile perch		Deep fried Nile perch		Deep fried Tilapia	
OCPs	AD	CHI	AD	CHI	AD	CHI	AD	CHI	AD	CHI	AD	CHI
	HQ	HQ	HQ	HQ	HQ	HQ	HQ	HQ	HQ	HQ	HQ	HQ
Oxychlordane	ND	ND	ND	ND	ND	ND	2.8E-05	3.3E-05	ND	ND	ND	ND
α-Chlordane	ND	ND	ND	ND	4.8E-05	5.8E-05	6.3E-05	7.6E-05	ND	ND	ND	ND
p, p'-DDE	4.3E-05	5.2E-05	3.7E-05	4.4E-05	5.3E-05	6.4E-05	2.3E-05	2.7E-05	4.6E-05	5.5E-05	7.9E-05	9.5E-05
Dieldrin	ND	ND	ND	ND	1.5E-03	1.8E-03	1.4E-03	1.7E-03	ND	ND	1.7E-03	2.0E-03
α- HCH	1.9E-02	2.3E-02	ND	ND	4.9E-03	6.0E-03	1.4E-02	1.7E-02	ND	ND	ND	ND
β- HCH	ND	ND	ND	ND	ND	ND	5.0E-02	6.1E-02	ND	ND	ND	ND
γ- HCH	4.1E-02	4.9E-02	ND	ND	1.6E-02	1.9E-02	3.5E-02	4.2E-02	3.5E-02	4.3E-02	1.8E-02	2.2E-02
α- Endosulfan	ND	ND	ND	ND	ND	ND	1.1E-05	1.3E-05	ND	ND	ND	ND
HCB	8.7E-05	1.1E-04	ND	ND	4.1E-05	4.9E-05	2.2E-04	2.7E-04	ND	ND	2.7E-04	3.2E-04
HI = ΣHQs	6.0E-02	7.2E-02	3.7E-05	4.4E-05	2.2E-02	2.7E-02	1.0E-01	1.2E-01	3.5E-02	4.3E-02	2.0E-02	2.5E-02

AD stands for adults, CHI for children, HQ for hazard quotient, HI for hazard index and ND for not determined, as their concentrations in fish products were <LOD.

products. The cancer and non-cancer risks were ranked low and insignificant respectively. The fish products are therefore safe for human

consumption and the organochlorine pesticides residue levels in the studied fish products do not represent a health risk to human beings.

However, continuous monitoring is required in order to minimize the building up of the studied organochlorine compounds in the aquatic biota

since they have the ability of increasing in concentration when they enter organisms at higher trophic niche such as human beings.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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